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TENSILE STRENGTHS OF MONTAUBAN MINE ROCKS

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Canadian Mining Technology Laboratories

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TENSILE STRENGTHS OF MONTAUBAN MINE ROCKS

by

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ABSTRACT

Tensile strength tests were performed on Montauban mine rocks (gneisses), originating from various stope hangingwalls. Beam tensile tests were adopted to obtain results representative of field conditions and useable in various stability analysis. Brazilian tensile tests were also performed for scientific comparison to beam test results.

The beam tensile strength results show that there is a correlation between tensile strength/modulus of elasticity and beam slenderness.

Beam tensile strength for these gneisses is slightly higher than Brazilian tensile strength.

KEYWORDS: beam tensile strength, Brazilian tensile strength, beam slenderness, gneiss, hangingwall.

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RÉSISTANCE EN TRACTION DE ROCHES DE LA MINE MONTAUBAN

par

M.C. Bétournay*, C. Lee** et M. Little***

RÉSUMÉ

Des essais en traction ont été faits sur des roches de la Mine Montauban (des gneiss) provenants de divers toits de chantiers. Des essais de traction de poutres ont été adoptés pour obtenir des valeurs représentatives des conditions en places et qui serviraient dans les diverses analyses de stabilité. Des essais de traction brésiliens ont été également faits pour fins de comparaisons scientifiques aux résultats d'essais de poutres.

Les résultats des essais de traction de poutres démontrent qu'il y a corrélation entre la résistance en traction/module d'élasticité et la ténuité de poutre.

La résistance en traction de poutre de ces gneiss est un peu plus élevée que la résistance en traction de disques brésiliens.

MOTS CLÉS: résistance en traction de poutre, résistance en traction brésilien, ténuité de poutre, gneiss, éponte supérieure.

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INTRODUCTION

A lab test campaign was undertaken to evaluate Montauban Mine rock strength properties. This campaign forms a part of the workscope of the Montauban Mine stability project. This report is related to the series of tensile tests performed on rock beams and rock discs. Compression test results are found elsewhere (1).

Tensile strength is required for assessment of mine roof stability, calculation of numerical model parameters and back analysis of roof failures.

Beam tests were performed because of:

1) the need to duplicate mechanical action encountered in-situ;
2) the requirement to use a test with a large sample to represent roof conditions;
3) the requirement to use a test that would subject a layered rock to valid tensile test conditions;
4) verification of size effects on strength.

For scientific value,Brazilian tests were also carried out to compare to beam test results. Discs for these tests were cut from core obtained from the same parent block as the beams.

Few beam, or beam vs Brazilian tensile tests have been performed in Canada even though various mine sites depend on layered rocks (schists, metasediments, gneisses, etc.) for the stability of underground openings.

ROCK SPECIMENS

The Montauban mine excavates gold which is disseminated in a gneissic terrain. The orebody, limited to a 2-3 m horizon, dips 20°. Various types of gneisses have been identified, Table 1, but each type is

repeated non-uniformly in a vertical succession. The gneissocity is pervasive, yielding well- to medium-banded rocks. Identification of the rock types was performed by mine geologists. Tensile samples originated from blocks (0.05-0.3 m^3) obtained from hangingwalls (roofs) of several stopes, Table 1.

SAMPLE PREPARATION

Beam Samples

Roof blocks were saw-cut into beam of rectangular prismatic shape. Various sizes were cut according to block geometry and test space limitations: 3 to 8 cm thick, 10 to 32 cm long and 7 to 15 cm wide. Several beams were cut from each rock block. This afforded the opportunity to evaluate size effects on strength and bending modulus of elasticity.

The upper and lower loading faces were grounded smooth and parallel to prevent torsion. The gneissocity was oriented parallel to the upper and lower beam surface, and therefore perpendicular to load direction.

Brazilian Samples

Drill cores were obtained from the parent material of beams. These cores, approximately 4.43 cm Ø, were saw-cut into discs and lathed for face parallelity, 1.53 to 1.95 cm thick. The gneissocity was oriented perpendicular to load.

TEST SET-UP

Beam Tests

The testing arrangement used in this program, Figure 1, consists

of a four point loading system to generate a uniform extreme-fibre tensile stress. The loading points are 18.9 mm steel rods; the loading spans are adjustable. The load is provided by a testing machine. The central deflection of the bottom chord is measured by an LVDT. A pen recorder plotted the load cell value versus LVDT displacement. The loading system was assembled at CANMET by Mr. B. Gorski and M.C. Bétournay.

Rock material does not have the same elastic modulus in tension and compression. Such double elasticity in bending of rock beams results in a shift of the neutral axis towards the upper beam surface, reducing the thickness of the compression zone. It was felt that the overestimation obtained by not considering the double elasticity of rock (lower tensile than compressive elasticity) was not important enough to carry out more detailed tests to obtain bottom and top chord strains. The solution used here is then based on uniform elastic behaviour.

The tensile strength was calculated using the following equation (2):

$$\sigma_{T(b)} = \frac{2Pl}{bh^2}$$

where P = total load applied in the form of two loading points, each P/2
l = half the beam length (2l) between the supports
b = beam width
h = beam thickness

The bending modulus of elasticity was obtained by using the formula (2):

$$E_b = \frac{46Pl^3}{27ybh^3}$$

where y = deflection at mid-span.

Brazilian Tests

Disc samples were loaded diametrically, Figure 2. Peak load cell

strain was used to measure failure load. The tensile strength was calculated using the following equation (3):

$$T_s = \frac{2P}{\pi DL}$$

where T_s = Brazilian tensile strength
P = failure load
D = disc diameter
L = disc thickness

RESULTS

Fifty-five beam tests and forty-nine Brazilian tests were performed.

Beam Tests

Table 2 outlines beam dimensions, strength and deformation results. Specimens containing serious flaws were considered unrepresentative and thus not used in subsequent analyses.

It was observed that the failure plane for intact rock was not vertical, but irregular, caused by small horizontal displacements along layers rich in mica. The failure plane was not always centrally located, but the failure surface was fresh except where it incorporated existing flaws.

There is a large variation in tensile strength/modulus of elasticity of beams cut from each block. There is also a variation in mechanical properties between samples of the same rock type but originating from different stopes.

Beams originating from the same parent block should yield approximately the same values (within bounds of material variability). The formulas used to calculate strength and modulus of elasticity compensate for varying geometries and failure load.

There are three possible explanations for such variability in the results:

1) there is a variation in mineralogy or component arrangement from sample to sample, for the same block parent;

2) there is an acute size vs strength/modulus of elasticity variation because of microfissures, gneissic structure;

3) there is an acute shape vs strength/modulus of elasticity variation.

Table 3 shows a tabulation of mineralogical variation between beam samples of blocks 195S1. Though there is some variation in quartz vs mica content, this is usually only 5%. Such a difference is insufficient to explain the range of tensile values (9.95 - 46.41 MPa). The rock structure remains almost the same from sample to sample.

It remains to be verified if there is any evidence of shape or size effects due to sample size and geometry.

Strictly on a thickness, or length, basis (Table 4) there is no clear relationship with strength or modulus of elasticity, e.g. strength increasing with decrease in thickness (lower volume, decrease in number and extent of weakening elements such as microfissures). Another index factor is necessary to clarify this. Taken from the elastic beam theory,

$$\sigma_T = \frac{WL^2}{2bh^2}$$

where σ_T = induced tension at the bottom chord of the sample, from a uniformly distributed load w.

the span L, with b and thickness h can be used in the form L^2/bh^2 to reexamine the results. Table 5 indicates a better relationship between this index (here named S_e, elastic slenderness index) and tensile strength/modulus of elasticity. Tensile strength and modulus of

elasticity (especially) increase when S_e is greater than 1.9, but there seems to be no obvious decrease in strength with the lower values of S_e available here ($S_e > 0.37$). For these lower values, up to $S_e = 1.9$, tensile strength/modulus of elasticity change little.

S_e is an indication of the beam slenderness. A higher value of S_e indicates a beam that is proportionately thinner, either because the span has increased or thickness decreased. It does not reflect volume effects.

The last facet to be examined is the influence of volume of rocks (and hence more microfissures, flaws, etc.) on rock strength. On a volume basis alone, Table 5, there is no obvious volume - strength/modulus of elasticity relationship. On the other hand, examining volume effects in beams with similar S_e values is inconclusive: it is only evident in some cases.

Therefore, it was accepted to base calculation of representative of lab tensile strength values and bending modulus of elasticity on beam samples with $S_e < 1.9$. This will eliminate results heavily influenced by slenderness effects. Table 6 displays these values and their mean. These are the values to be used in conjunction with stability assessments.

Brazilian Tests

Table 7 outlines disc dimensions, strengths and failure modes related to these tests. Specimen subjected to experimental problems were not included in subsequent analyses.

The failure was not always vertical, as expected of this type of test. Some fractures were angled, in part due to the horizontal offset caused by weak gneissic planes.

The level of variation between tensile strengths of discs of the

same parent block is small and can be explained by inherent material variation.

The tensile values obtained can thus be readily averaged for each parent block. The averages are found in Table 8.

Comparison of Beam and Brazilian Tensile Strengths

It is possible to carry out a comparison of beam strengths (for $S_e < 1.9$) and Brazilian strengths, because the discs were obtained from one parent beam.

Notwithstanding the fact that only one beam value exists for comparison, the strength values between the two tests is similar, but the Brazilian strength tests usually yield lower values, Table 9.

The standard deviation levels seen in Brazilian tests is lower than those in beam tests, an indication of volume effects (discs are ~ 7 to 100 times smaller).

CONCLUSIONS

1) Beam tensile tests of samples with a well developed gneissocity yield a range of tensile strength/modulus of elasticity for the same rock block.

2) This variation is explained by considering a direct relationship between tensile strength/modulus of elasticity and elastic beam slenderness ratio $S_e = L^2/b^2h^2$. This relationship is better developed for modulus of elasticity values.

3) Beams with similar S_e ratios major may not show volume effects (larger volume, weaker results).

4) Tensile strength/modulus of elasticity varies from rock type to rock type and for the same rock type originating from different stratas.

5) Brazilian tensile strengths are slightly lower than beam tensile strengths.

6) Brazilian strengths averages have a lower standard deviation than beam strength averages, attributed to volume effects.

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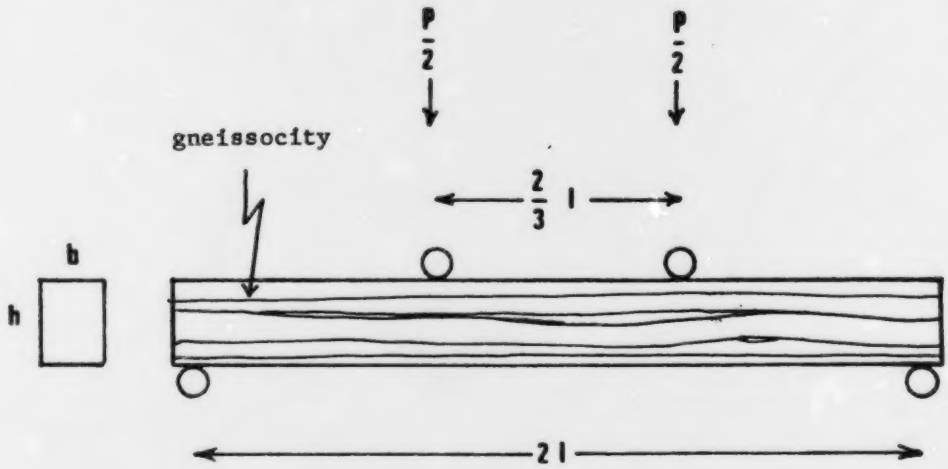

Fig. 1. Beam-type testing apparatus used for tensile tests.

P = Total applied load.

2ℓ = Bottom beam span.

b = Beam width.

h = Beam thickness.

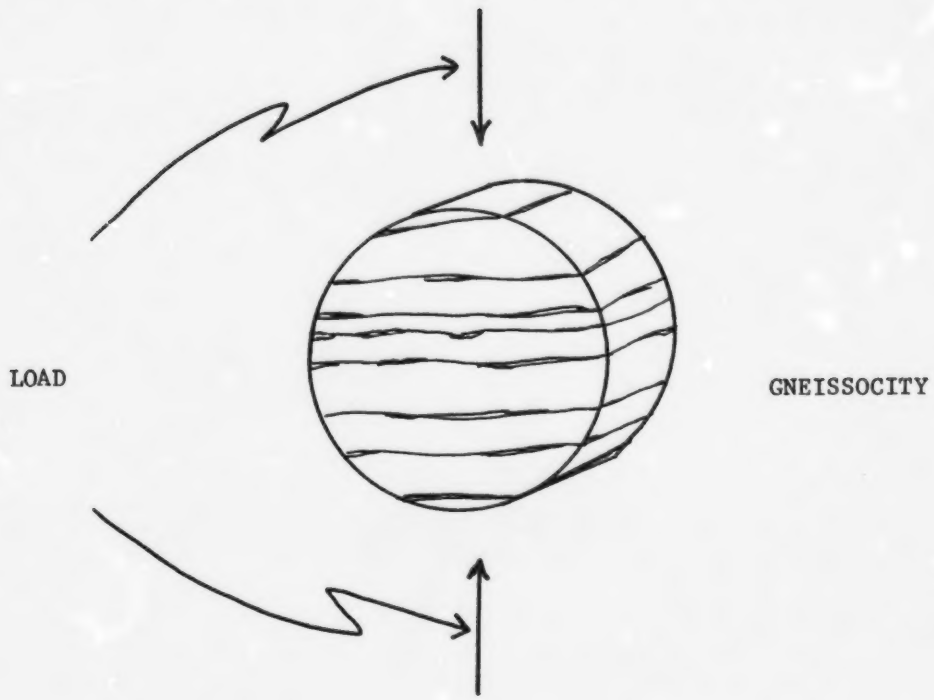

Fig. 2. Brazilian test set-up. Load normal to the gneissocity

TABLE 1 - HANGINGWALL ROCK TYPES AND LOCATION OF SUPPLY OF HANGINGWALL ROCK BLOCKS FOR TENSILE TESTS

STOPE	HANGING WALL ROCK TYPE
045N	A
025N	A
030S	AH
040S	A
060S	A
080S	Gqmb
100S	Gqmb
120S	Gqmb
135S	Gqmb
✓ 165S	Gqmb
✓ 195S	Gqmb
215S	Gqmb, A
230S	Gqm
245S	Gqmb
✓ 255S	Gqm
✓ 280S	Gqm
285S	Gqm
300S	Gqm
330S	Gqm

G: Gneiss
A: Amphibolite
H: Hornblende
q: quartz
m: muscovite
b: biotite
g: garnet
✓: hangingwall block(s)

TABLE 1 (Cont'd)

STOPE	HANGING WALL ROCK TYPE
✓ 360S	Gqmb
375S	Gqm
405S	Gqm
420S	Gqm
435S	
✓ 450S	Gqmb
480S	
490S	Gqmb
M335	Gqmb
M355	Gqmb
M375	Gqmb
M395	Gqmb
M415	Gqmb
✓ M435A	Gqbg
M435B	Gqmb
✓ M455A	Gqbg
✓ M455B	Gqmb
M470	Gqbg

G: Gneiss
A: Amphibolite
H: Hornblende
q: quartz
m: muscovite
b: biotite
g: garnet
✓: hangingwall block(s)

TABLE 2
BEAM TENSILE TEST RESULTS

SAMPLE	ROCK TYPE	THICKNESS (h) (cm)	WIDTH (b) (cm)	SPAN (2 1) (cm)	FAILURE LOAD (kN)	FAILURE CENTRAL DEFORMATION (cm)	TENSILE STRENGTH (σ_t) (MPa)	BENDING MODULUS OF ELASTICITY (E_b) (GPa)	PRE-FAILURE CONDITION	FAILURE MODE
165S*2†1≠	QMB	4.5	5.3	12.6	5.46	0.0083	6.47	5.91	INTACT	irregular vertical
165S2-2	QMB	5.4	7.4	12.2	9.83	0.0305	5.60	1.10	FLAWED	along flaw
165S2-3	QMB	4.4	6.5	14.2	6.59	0.0243	7.49	3.05	FLAWED	along flaw
165S3-1	QMB	4.8	9.2	15.0	21.95	0.0689	15.64	2.29	INTACT	irregular vertical
165S3-2	QMB	6.3	10.2	28.8	15.95	0.0185	11.39	17.37	INTACT	irregular vertical
195S1-1	QMB	4.7	7.6	13.2	12.56	0.0319	9.95	2.50	INTACT	irregular vertical
195S1-2	QMB	4.8	10.6	16.8	12.09	0.0363	8.32	2.87	FLAWED	along flaw
195S1-3	QMB	8.8	9.4	31.6	34.19	0.0352	14.84	10.19	INTACT	irregular vertical
195S1-4	QMB	5.3	12.9	12.8	43.72	0.0283	15.56	3.68	INTACT	irregular vertical
195S1-5	QMB	4.2	15.0	17.0	30.81	0.0236	19.91	12.52	INTACT	irregular vertical
195S1-6	QMB	6.6	14.6	27.4	54.19	0.0427	23.43	13.38	INTACT	irregular vertical
195S1-7	QMB	2.9	8.0	11.8	15.79	0.0195	27.69	14.51	INTACT	irregular vertical
195S1-8	QMB	3.8	7.9	15.4	22.19	0.0379	29.95	10.51	INTACT	irregular vertical
195S1-9	QMB	2.6	5.4	12.6	8.37	0.0064	29.13	59.58	INTACT	irregular vertical

* stope number
† rock block number
≠ beam sample number

QM = quartz muscovite gneiss
QMB = quartz muscovite biotite gneiss
A = amphibolite
QBG = quartz biotite garnet gneiss

TABLE 2 (Cont'd)

SAMPLE	ROCK TYPE	THICKNESS (h) (cm)	WIDTH (b) (cm)	SPAN (2 1) (cm)	FAILURE LOAD (kN)	FAILURE CENTRAL DEFORMATION (cm)	TENSILE STRENGTH (σ_t) (MPa)	BENDING MODULUS OF ELASTICITY (E_b) (GPa)	PRE-FAILURE CONDITION	FAILURE MODE
195S1-10	QMB	3.6	7.8	10.4	15.21	0.0399	15.80	2.58	INTACT	irregular vertical
195S1-11	QMB	3.3	5.8	26.0	7.27	0.0394	29.92	33.12	INTACT	irregular vertical
195S1-13	QMB	3.2	6.1	12.2	9.93	0.0305	19.55	6.46	INTACT	irregular vertical
195S1-14	QMB	3.8	7.6	11.4	14.14	0.0276	14.82	3.98	INTACT	irregular vertical
195S1-15	QMB	1.6	9.7	32.6	3.53	0.0584	46.41	112.37	INTACT	irregular vertical
255S2-1	QM	4.2	7.6	16.0	13.81	0.0564	16.49	3.79	INTACT	irregular vertical
255S2-2	QM	4.2	9.4	16.8	7.21	0.0354	7.35	3.01	FLAWED	along flaw
255S2-3	QM	5.8	10.1	13.6	21.45	0.0404	8.65	1.47	INTACT	irregular vertical
255S2-4	QM	5.9	9.6	19.0	10.00	0.0152	5.72	4.94	FLAWED	along flaw
255S2-5	QM	5.0	8.0	22.0	18.02	0.0438	19.83	9.32	FLAWED	irregular vertical
255S2-6	QM	3.6	21.4	19.8	7.09	0.0428	5.09	2.78	FLAWED	along flaw
280S1-1	QM	8.8	14.9	33.4	45.91	0.0319	13.33	11.34	INTACT	irregular vertical
280S1-2	QM	6.2	8.6	22.8	31.63	0.0493	21.81	7.89	INTACT	irregular vertical
280S1-3	QM	4.6	9.7	20.0	11.98	0.0276	11.67	7.84	INTACT	irregular vertical

TABLE 2 (Cont'd)

SAMPLE	ROCK TYPE	THICKNESS (h) (cm)	WIDTH (b) (cm)	SPAN (2 1) (cm)	FAILURE LOAD (kN)	FAILURE CENTRAL DEFORMATION (cm)	TENSILE STRENGTH (σ_t) (MPa)	BENDING MODULUS OF ELASTICITY (E_b) (GPa)	PRE-FAILURE CONDITION	FAILURE MODE
280S2-1	QM	4.8	5.8	15.6	8.08	0.0229	9.49	4.54	INTACT	irregular vertical
280S2-2	QM	7.1	10.1	20.0	27.72	0.0744	10.89	1.76	FLAWED	along flaw
280S2-3	QM	6.9	17.1	19.6	44.98	0.0660	10.83	1.94	INTACT	irregular vertical
280S2-4	QM	7.4	10.6	20.0	39.21	0.0288	13.58	5.47	INTACT	irregular vertical
280S2-5	QM	4.4	13.3	18.0	9.30	0.0428	6.54	2.42	INTACT	irregular vertical
280S2-6	QM	4.7	6.6	9.2	6.39	0.0363	4.04	0.43	INTACT	irregular vertical
360S1-2	QMB	3.9	9.4	13.8	6.16	0.0138	5.99	4.58	INTACT	irregular vertical
360S1-3	QMB	2.2	15.1	14.4	1.92	0.0635	3.79	1.20	INTACT	irregular vertical
360S2-1	QMB	6.5	13.5	16.8	33.84	0.0594	10.03	1.58	INTACT	irregular vertical
360S2-2	QMB	6.3	13.9	16.8	27.19	0.0414	8.33	1.94	INTACT	irregular vertical
360S2-3	QMB	6.0	7.7	16.8	14.32	0.0395	8.73	2.24	INTACT	irregular vertical
360S2-4	QMB	4.0	8.9	18.0	5.35	0.0046	6.80	25.78	INTACT	irregular vertical
380S1-1	QM	7.7	12.5	20.8	21.53	0.0468	6.04	1.54	FLAWED	along flaw
380S1-1	QM	7.1	14.8	18.2	86.28	0.0559	21.16	3.80	INTACT	irregular vertical

TABLE 2 (Cont'd)

SAMPLE	ROCK TYPE	THICKNESS (h) (cm)	WIDTH (b) (cm)	SPAN (2 l) (cm)	FAILURE LOAD (kN)	FAILURE CENTRAL DEFORMATION (cm)	TENSILE STRENGTH (σ_t) (MPa)	BENDING MODULUS OF ELASTICITY (E_b) (GPa)	PRE-FAILURE CONDITION	FAILURE MODE
450S1-1	QMB	5.8	12.3	21.2	42.42	0.0484	21.84	7.51	INTACT	irregular vertical
450S1-2	QMB	6.2	9.0	18.2	32.37	0.0309	17.12	6.37	INTACT	irregular vertical
450S1-3	QMB	6.0	12.1	21.4	42.46	0.0422	20.96	8.14	INTACT	irregular vertical
450S1-4	QMB	6.0	8.9	18.2	38.79	0.0322	22.03	8.04	INTACT	irregular vertical
450S2-1	QMB	4.9	5.6	14.8	15.93	0.0317	17.65	5.37	INTACT	irregular vertical
450S2-2	QMB	4.9	12.9	11.8	41.86	0.0708	16.08	1.40	INTACT	irregular vertical
450S2-3	QMB	6.3	8.7	17.4	21.98	0.0599	11.14	1.92	INTACT	loading point
450S2-4	QMB	7.7	10.9	20.0	23.25	0.0127	7.23	6.36	FLAWED	along flaw
450S2-5	QMB	7.6	11.2	20.0	31.86	0.0382	9.90	2.94	INTACT	irregular vertical
450S2-6	QMB	2.5	5.5	22.2	1.91	0.0236	12.32	21.92	INTACT	irregular vertical
450S2-7	QMB	4.2	5.7	15.0	14.79	0.0357	22.21	7.19	INTACT	irregular vertical
450S2-8	QMB	3.2	5.5	12.4	1.98	0.0109	4.35	4.09	INTACT	irregular vertical
450S3-1	QMB	10.2	16.4	27.4	15.12	0.0123	2.44	3.12	INTACT	irregular vertical
M435A3-1	QBG	6.7	16.1	16.4	66.16	0.0628	15.10	2.08	INTACT	irregular vertical

TABLE 2 (Cont'd)

SAMPLE	ROCK TYPE	THICKNESS (h) (cm)	WIDTH (b) (cm)	SPAN (2 l) (cm)	FAILURE LOAD (kN)	FAILURE CENTRAL DEFORMATION (cm)	TENSILE STRENGTH (σ_t) (MPa)	BENDING MODULUS OF ELASTICITY (E_b) (GPa)	PRE-FAILURE CONDITION	FAILURE MODE
M435A3-2	QBG	6.0	9.5	16.8	28.56	0.0520	14.11	2.75	INTACT	irregular vertical
M455A2-1	QBG	12.5	12.2	37.8	12.79	0.1622	2.54	0.38	FLAWED	along flaw
M455B1-1	QMB	7.1	5.4	18.2	5.35	0.0352	3.58	1.01	FLAWED	along flaw
M455B1-2	QMB	5.5	7.0	13.0	25.25	0.0285	15.50	3.56	INTACT	irregular vertical
M455B1-3	QMB	5.0	6.5	11.6	21.02	0.0361	15.01	2.38	INTACT	irregular vertical
M455B1-4	QMB	8.5	10.5	20.4	55.53	0.0666	14.93	2.34	INTACT	irregular vertical
M455B1-5	QMB	7.5	14.1	20.6	26.98	0.0327	7.04	2.62	INTACT	irregular vertical
M455B1-6	QMB	7.6	7.7	20.4	41.74	0.0571	19.15	3.91	INTACT	irregular vertical
M455B1-7	QMB	6.2	7.1	18.2	7.28	0.0480	4.88	1.17	FLAWED	irregular vertical
M455B1-8	QMB	6.5	6.7	17.6	21.25	0.0276	13.29	4.95	INTACT	irregular vertical
M455B1-9	QMB	6.8	8.9	16.2	18.51	0.0411	7.33	1.48	FLAWED	along flaw
M455B1-10	QMB	4.6	10.5	11.8	7.86	0.0341	4.17	0.79	FLAWED	irregular vertical
M455B1-11	QMB	7.5	7.8	20.0	43.26	0.0352	19.72	6.36	INTACT	irregular vertical

TABLE 3
MINERALOGICAL VARIATION VERSUS STRENGTH
FFR 195S1 BEAM SAMPLES

SAMPLE	% DISTRIBUTION QUARTZ-MICA	MINERALOGY STRUCTURE	THICKNESS (cm)	WIDTH (cm)	SPAN (cm)	TENSILE STRENGTH (MPa)	BENDING MODULUS OF ELASTICITY (GPa)
195S-1	70 - 30	Gneiss banding, mica layering	4.7	7.6	13.2	9.95	2.50
195S1-3	80 - 20	Gneissic banding	8.8	9.4	31.6	14.84	10.19
195S1-4	80 - 20	Gneissic banding	5.3	12.9	12.8	15.56	3.68
195S1-5	80 - 20	Gneissic banding	4.2	15.0	17.0	19.91	12.52
195S1-6	85 - 15	Gneissic banding	6.6	14.6	27.4	23.43	13.38
195S1-7	80 - 20	Gneissic banding	2.9	8.0	11.8	27.69	14.51
195S1-8	85 - 15	Gneissic banding	3.8	7.9	15.4	29.95	10.51
195S1-9	85 - 15	Gneissic banding	2.6	5.4	12.6	29.13	59.58
195S1-10	85 - 15	Gneissic banding	3.6	7.8	10.4	15.80	2.58
195S1-11	80 - 20	Gneissic banding	3.3	5.8	26.0	29.92	33.12
195S1-13	80 - 20	Gneissic banding	3.8	6.1	12.2	19.55	6.46
195S1-14	80 - 20	Gneissic banding	3.8	7.6	11.4	14.82	3.98
195S1-15	85 - 15	Gneissic banding	1.6	9.7	32.6	46.41	112.37

TABLE 4
COMPARISON OF TENSILE STRENGTH AND MODULUS OF ELASTICITY FOR 195S1 BEAMS BY THICKNESS OR SPAN ALONE

THICKNESS (cm)	TENSILE STRENGTH (MPa)	MODULUS OF ELASTICITY (GPa)
8.8	14.84	10.19
6.6	23.43	13.38
5.3	15.56	3.68
4.7	9.95	2.50
4.2	19.91	12.52
3.8	29.95	10.51
3.8	14.82	3.98
3.6	15.80	2.58
3.3	29.92	33.12
3.2	19.55	6.46
2.9	27.69	14.51
2.6	29.13	59.58
1.6	46.41	112.37

SPAN (cm)	TENSILE STRENGTH (MPa)	MODULUS OF ELASTICITY (GPa)
32.6	46.41	112.37
31.6	14.84	10.19
27.4	23.43	13.38
26.0	29.92	33.12
17.0	19.91	12.52
15.4	29.95	10.51
13.2	9.95	2.50
12.8	15.56	3.68
12.6	29.13	59.58
12.2	19.55	6.46
11.8	27.69	14.51
11.4	14.82	3.98
10.4	15.80	2.58

TABLE 5

COMPARISON OF TENSILE STRENGTH AND MODULUS OF ELASTICITY ACCORDING TO ELASTIC BEAM CONSTANT $\frac{L^2}{bh^2}$ FOR PARENT BLOCKS AND SUBDIVIDED BEAMS

$\frac{L^2}{bh^2}$	Volume (cm^3)	σ_T (MPa)	E_b (GPa)
		165S3	
1.06	662	15.64	2.29
1.94	1850	11.39	17.37
		195S1	
0.45	875	15.56	3.68
1.04	471	9.95	2.50
1.07	292	15.80	2.58
1.09	1071	19.91	12.52
1.18	329	14.84	10.19
1.18	2640	23.43	13.58
1.37	2614	14.82	3.98
2.07	462	29.95	10.51
2.38	238	19.55	6.46
3.71	273	27.69	14.51
4.35	176	29.13	59.58
10.70	498	29.92	33.12
42.80	506	46.41	112.37
		255S2	
0.54	796	8.65	1.47
1.91	510	16.49	3.79
2.42	880	19.83	9.32
		280S1	
0.97	4379	13.33	11.34
1.57	1215	21.81	7.89
1.95	892	11.67	7.84
		280S2	
0.47	2312	10.83	1.94
0.58	285	4.04	0.43
0.69	1569	13.58	5.47
1.26	1053	6.54	2.42
1.82	434	9.49	4.54

TABLE 5 (Cont'd)

$\frac{L^2}{bh^2}$	Volume (cm^3)	σ_T (MPa)	E_b (GPa)
		360S1	
1.33	506	5.99	4.58
2.85	478	3.79	1.20
		360S2	
0.50	1474	10.03	1.58
0.51	1471	8.33	1.94
1.02	776	8.73	2.24
2.27	641	6.80	25.78
		450S1	
0.95	1016	17.12	6.37
1.04	972	22.03	8.04
1.05	1554	20.96	8.14
1.09	1512	21.84	7.51
		450S2	
0.45	746	16.08	1.40
0.60	1702	9.90	2.94
1.63	406	17.65	5.37
2.24	359	22.21	7.19
2.73	218	4.35	4.09
14.34	305	12.32	21.92
		M435A3	
0.37	1769	15.10	2.08
0.83	958	14.11	2.75
		M455B1	
0.54	2178	7.04	2.62
0.55	1820	14.93	2.34
0.80	500	15.50	3.56
0.83	377	15.01	2.38
0.91	1170	19.72	6.36
0.94	1193	19.15	3.91
1.09	766	13.29	4.95

TABLE 6

AVERAGE TENSILE STRENGTH AND MODULUS OF ELASTICITY FOR HANGINGWALL ROCKS OF THE MONTAUBAN MINE†

Stope	Block Number	Rock Type	Sample Number		Tensile Strength (MPa)		Modulus of Elasticity (GPa)
165S	2	QMB	1		6.47		5.91
				mean	6.47		5.91
165S	3	QMB	1		15.64		2.29
				mean	15.64		2.29
195S	1	QMB	1		9.95		2.50
	1	QMB	3		14.84		10.19
	1	QMB	4		15.56		3.68
	1	QMB	5		19.91		12.52
	1	QMB	6		23.43		13.38
	1	QMB	10		15.80		2.58
	1	QMB	14		14.82		3.98
				mean	16.33	±4.25	6.61
255S	2	QM	3		8.65		1.47
				mean	8.65		1.47
280S	1	QM	1		13.33		11.34
	1	QM	2		21.81		7.89
				mean	17.57	±4.24	9.62
280S	2	QM	1		9.49		4.54
	2	QM	3		10.83		1.94
	2	QM	4		13.58		5.47
	2	QM	5		6.54		2.42
	2	QM	6		4.84		0.43
				mean	8.88	±3.47	2.96
360S	1	QMB	2		5.99		4.58
				mean	5.99		4.58
360S	2	QMB	1		10.03		1.58
	2	QMB	2		8.33		1.94
	2	QMB	3		8.73		2.24
				mean	9.03	±0.89	1.92

† representing those samples with $L^2/bh^2 < 1.9$ and that were not flawed prior to testing.

TABLE 6 (Cont'd)

Stope	Block Number	Rock Type	Sample Number		Tensile Strength (MPa)	Modulus of Elasticity (GPa)
380S	1	QM	2		21.16	3.80
				mean	21.16	3.80
450S	1	QMB	1		21.84	7.51
	1	QMB	2		17.12	6.37
	1	QMB	3		20.96	8.14
	1	QMB	4		22.03	8.04
				mean	20.49 ±2.29	9.39
450S	2	QMB	1		17.65	5.37
	2	QMB	2		16.08	1.40
	2	QMB	5		9.90	2.94
				mean	14.54 ±4.10	9.71
450S	3	QMB	1		2.44	3.12
				mean	2.44	3.12
M435A	3	QBG	1		15.10	2.08
	3	QBG	2		14.11	2.75
				mean	14.61 ±0.50	2.41
M455B	1	QBG	2		15.50	3.56
	1	QBG	3		15.01	2.38
	1	QBG	4		14.93	2.34
	1	QBG	5		7.04	2.62
	1	QBG	6		19.15	3.91
	1	QBG	8		13.29	4.95
	1	QBG	11		19.72	6.36
				mean	14.95 ±4.21	3.73

TABLE 7
BRAZILIAN TENSILE TEST DATA

SAMPLE NUMBER	DIAMETER (mm)	LENGTH (mm)	PEAK LOAD (kN)	BRAZILIAN σ_t (MPa)	COMMENTS
195S1-3 B1	44.22	18.82	20.63	15.76	angled fracture
195S1-3 B2	44.26	18.46	23.09	17.98	vertical fracture
195S1-3 B3	44.28	18.38	19.88	15.54	vertical fracture
195S1-3 B4	44.38	17.90	22.05	17.65	vertical fracture
195S1-6 B1	44.22	16.26	18.35	16.23	vertical fracture
280S1-1 B1	44.32	17.20	13.88	11.58	vertical fracture
280S1-1 B2	44.26	19.54	15.42	11.34	vertical fracture
280S1-1 B3	44.20	17.66	13.16	10.73	vertical fracture
280S1-1 B4	44.22	19.06	-----	-----	vertical fracture experimental foul-up
280S1-1 B5	44.26	15.68	22.98	21.06	vertical fracture wooden buffers used 10 minute duration

TABLE 7 (Cont'd)

SAMPLE NUMBER	DIAMETER (mm)	LENGTH (mm)	PEAK LOAD (kN)	BRAZILIAN σ_t (MPa)	COMMENTS
280S1-2 B2	44.44	17.46	12.44	10.20	vertical fracture
280S2-3 B1	44.28	18.54	11.93	9.24	vertical fracture
280S2-3 B2	44.22	17.16	15.72	13.18	vertical fracture
280S2-3 B3	44.24	19.46	14.26	10.53	vertical fracture
280S2-3 B4	44.24	18.24	14.81	11.68	vertical fracture
280S2-3 B5	44.20	18.64	15.28	11.79	vertical fracture
280S2-3 B6	44.20	18.48	15.93	12.40	vertical fracture
280S2-3 B7	44.22	18.34	13.77	10.80	vertical fracture
280S2-4 B1	44.32	17.88	14.53	11.67	vertical fracture
280S2-4 B2	44.30	18.00	16.58	13.23	vertical fracture
280S2-4 B3	44.30	18.10	15.81	12.54	vertical fracture

TABLE 7 (Cont'd)

SAMPLE NUMBER	DIAMETER (mm)	LENGTH (mm)	PEAK LOAD (kN)	BRAZILIAN σ_t (MPa)	COMMENTS
280S2-4 B4	44.32	18.02	14.02	11.17	vertical fracture
360S2-1 B1	44.38	18.22	14.37	11.30	vertical fracture
360S2-1 B2	44.38	18.50	13.49	10.45	vertical fracture
360S2-1 B3	44.32	17.30	9.26	7.68	vertical fracture
360S2-1 B4	44.32	18.68	13.37	10.27	vertical fracture
360S2-1 B5	44.36	19.06	13.16	9.90	vertical fracture
360S2-1 B6	44.38	18.44	9.09	7.07	vertical fracture
360S2-2 B1	44.34	17.88	12.12	9.72	vertical fracture
360S2-2 B2	44.36	18.16	21.35	16.85	vertical fracture
360S2-2 B3	44.30	17.52	12.40	10.16	vertical fracture
360S2-2 B4	44.30	17.64	15.12	12.30	vertical fracture
360S2-2 B5	44.34	17.82	14.81	11.92	vertical fracture

TABLE 7 (Cont'd)

SAMPLE NUMBER	DIAMETER (mm)	LENGTH (mm)	PEAK LOAD (kN)	BRAZILIAN σ_t (MPa)	COMMENTS
360S2-2 B6	44.38	17.14	10.51	8.79	vertical fracture
380S1-1 B1	44.42	17.46	20.63	16.92	angled fracture
380S1-2 B2	44.44	18.44	23.56	18.28	crushed
380S1-2 B3	44.40	17.40	18.19	18.19	angled fracture
450S2-5 B1	44.52	16.82	7.26	6.16	vertical fracture
450S2-5 B2	44.60	17.18	9.72	8.07	vertical fracture
450S2-5 B3	44.34	17.44	6.26	5.15	vertical fracture
M455A2-1 B1	44.40	16.20	14.48	12.81	angled fracture
M455A2-1 B2	44.38	19.16	21.00	15.71	vertical fracture
M455A2-1 B3	44.32	17.48	15.95	13.10	angled fracture
M455A2-1 B4	44.34	18.90	20.14	15.28	angled fracture
M455A2-1 B5	44.36	17.78	11.12	8.96	angled fracture

TABLE 7 (Cont'd)

SAMPLE NUMBER	DIAMETER (mm)	LENGTH (mm)	PEAK LOAD (kN)	BRAZILIAN σ_t (MPa)	COMMENTS
M455B1-6 B1	44.14	15.66	16.46	15.15	vertical fracture
M455B1-6 B2	44.18	16.54	18.98	16.52	vertical fracture
M455B1-6 B3	44.18	15.34	16.88	15.84	vertical fracture
M455B1-6 B4	44.24	16.08	12.95	11.58	angled fracture

TABLE 8

AVERAGE BRAZILIAN TENSILE STRENGTH

Discs from Parent Beam	Tensile Strength	
455B1-6	15.15	
	16.52	
	15.84	
	11.58	
	mean 14.77	±2.20
455A2-1	12.81	
	15.71	
	13.10	
	15.28	
	8.96	
	mean 13.17	±3.11
195S1-3	15.76	
	17.98	
	15.54	
	17.65	
	mean 16.73	±1.25
195S1-6	16.23	
	mean 16.23	
360S2-2	9.72	
	16.85	
	10.16	
	12.30	
	11.92	
	8.79	
	mean 11.62	±2.87
380S1-2	16.92	
	18.28	
	18.19	
	mean 17.80	±0.76
280S1-1	11.58	
	11.34	
	mean 11.46	±0.12
280S1-2	10.20	
	mean 10.20	

TABLE 8 (Cont'd)

Parent Beam	Tensile Strength	
280S2-3	9.24	
	13.18	
	10.53	
	11.68	
	11.79	
	12.40	
	10.80	
	mean 11.37	±1.30
280S2-4	11.67	
	13.23	
	12.54	
	11.17	
	mean 12.15	±0.92
360S2-1	11.30	
	10.45	
	7.68	
	10.27	
	9.90	
	7.07	
	mean 9.45	±1.68
450S2-5	6.16	
	8.07	
	5.15	
	mean 6.46	±1.48

TABLE 9

COMPARISON OF BEAM TESTS AND BRAZILIAN TEST RESULTS

Parent Beam	Beam Tensile Strength (MPa)	Brazilian Tensile Strength (MPa)
195S1-3	14.84	16.73 ±1.25
195S1-6	23.43	16.23
280S1-1	13.33	11.46 ±0.12
280S1-2	21.81	10.20
280S2-3	10.83	11.37 ±1.30
280S2-4	13.58	12.15 ±0.92
360S2-1	10.03	9.45 ±1.68
360S2-2	8.33	11.62 ±2.87
380S1-2	21.16	17.80 ±0.76
450S2-5	9.90	6.46 ±1.48
M455A2-1	-----	13.17 ±3.11
M455B1-6	19.15	14.77 ±2.20